Exploring Multi-programming Applications in the NISQ Era

Siyuan Niu, Aida Todri-Sanial

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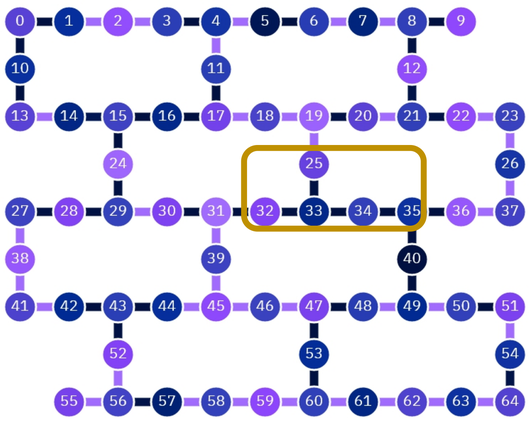
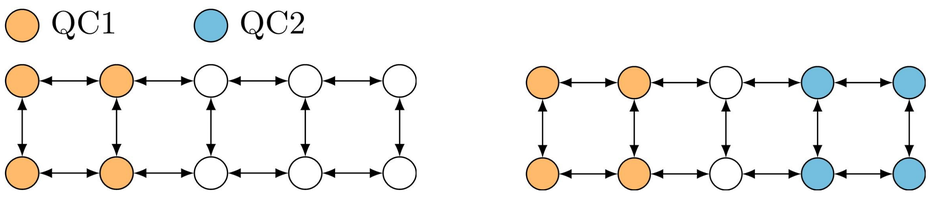
Introduction



- **Limited** hardware connectivity
- Unavoidable **error** rates
- Only **small** circuits can obtain reliable results
- **Long** waiting time

- Hardware throughput: **8%**
- Total pending jobs: **1038**

Motivation



(a) Hardware throughput = 40%

(b) Hardware throughput = 80%

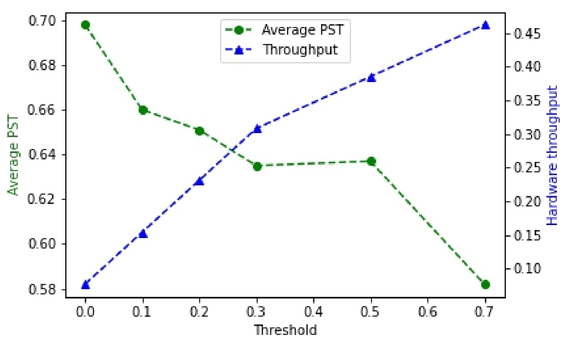
Key ideal: execute multiple circuits simultaneously to increase the hardware throughput and total runtime.

The multi-programming mechanism

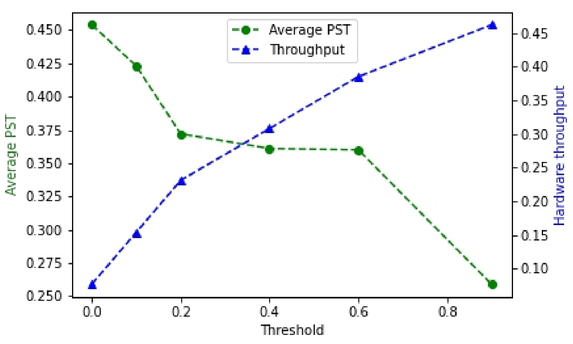
Which factors should we consider to build a multi-programming technique?

- Crosstalk
- Partition qubits to reliable regions
- Qubit mapping (routing)
- Task scheduling
- Number of simultaneous circuits

Hardware throughput vs Circuit fidelity



(a) 4mod5-v1_22 result



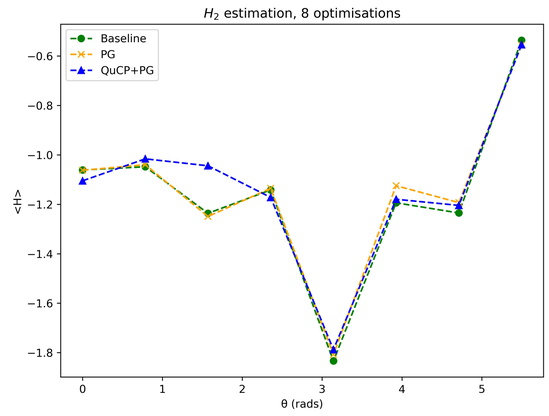
(b) alu-v0_27 result

- Experiment setup
  - Execute different number of the same circuit on IBM Q 65 Manhattan.
  - Report the relation between hardware throughput and circuit fidelity.
- Results
  - # parallel circuit executions: one to six
  - Hardware throughput: 7.7% to 46.2%
  - Significant fidelity loss when hardware throughput is over **38%.**

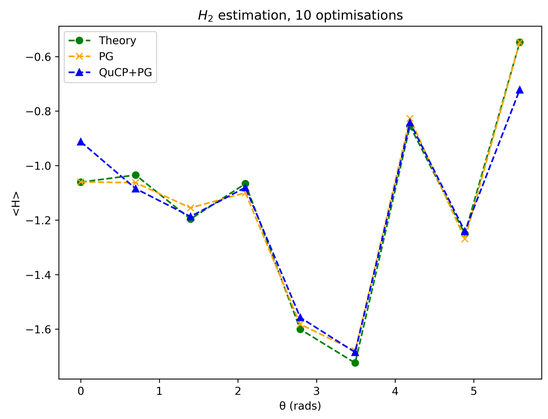
Multiprogramming and VQE

- VQE limitation
  - Split the computation into $O(N^4)$ sub-problems, introducing a large overhead of measurement circuits.
- Pauli grouping
  - Grouping commuting Pauli terms and measure them simultaneously.
- Idea
  - Apply multiprogramming to Pauli grouping

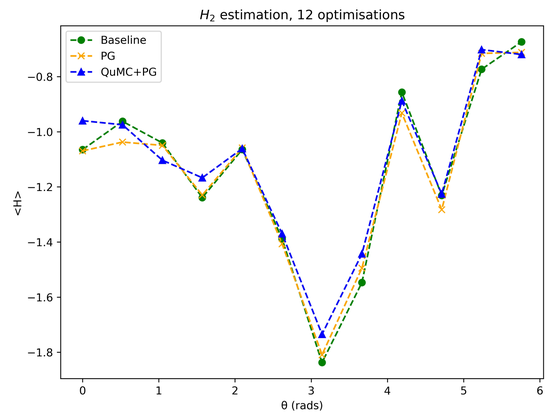
- Experiment setup
  - Estimate groud state energy of H_2
    - Hamiltonian: $\{II, IZ, ZI, ZZ, XX\}$
  - Heuristic ansatz state
  - Two repetitions
  - *RyRz* on each qubit



(a) 8 optimizations with 16 measurements.



(b) 10 optimizations with 20 measurements.

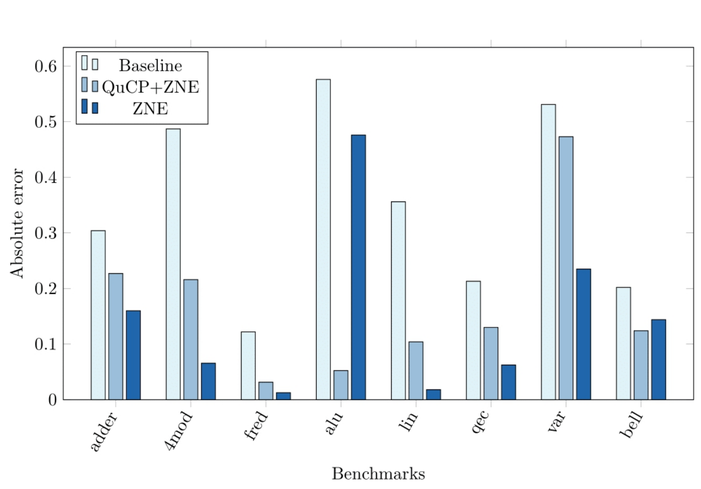


(c) 12 optimizations with 24 measurements.

- Results
  - Hardware throughput can be up to **73.8%** with an error rate of less than 10%.

Multiprogramming and ZNE

- Zero noise extrapolation (ZNE) error mitigation.
  - Noise-scaling
  - Extrapolation
  - Extra circuit overhead



- No ZNE (baseline)
- ZNE+multiprogramming
- ZNE

- Results
  - The error rate is reduced by **2x** without any circuit overhead.

References

[1] S.Niu et al. arxiv.2112.00387, 2021.
[2] S.Niu et al. arxiv.2102.05321, 2021.
[3] P.Gokhale et al. QCE 2020.
[4] Y.Li et al. PRX 2017.

Acknowledgment

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